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ORIGINAL ARTICLE

A statistical model for predicting the retrieval rate of separated instruments and clinical decision-making

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instrument fracture;
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separated instruments;
statistical model

Abstract *Background/purpose:* There are controversial opinions about the prognosis of the retrieval of a separated instrument from the root canal. The aim of the study was to establish a statistical model to predict the success rate of the retrieval of separated instruments and to aid clinicians with decision-making.
Materials and methods: In retrospective studies, information on the tooth position, the root canal curvature, and the depth and length of separated instruments were collected in 210 clinical cases with separated instruments in the lower segments of curved root canals. The correlations of these factors and the retrieval rate of separated instruments were analyzed. Two factors with significant correlations were chosen and a regression equation was established using stepwise multivariate logistic regression analysis. In the verification study, the efficiency of the statistical model was verified by 63 new cases.
Results: The root canal curvature and depth of the separated instruments are major factors affecting the retrieval rate of broken instruments. The retrieval rate of separated instruments

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decreased gradually with the increase of root canal curvature or the depth of the instrument. A regression equation was established correlating these two factors. The predicted accuracy rate of the regression equation was 94.3% for successful retrieval, and 80.0% for failed retrieval.

Conclusion: A statistical model relating to root canal curvature and depth of separated instruments was established to evaluate the retrieval rate of separated instruments, and the result of this formulation may provide clues for clinical decision-making.

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Introduction

Instrument separation is a common complication of root canal therapy. Literature shows the incidence rate of fractures is ~0.7—7.4% for stainless steel instruments and about 0.4—5% for nickel—titanium instruments.[1] Wu et al[2] reported that the fracture rate of Protaper in 2654 prepared teeth was ~2.6%. A separated instrument in the root canal interferes with root canal cleaning, shaping, filling, and negatively affects the patient's experience. The ideal solution of the problem is to remove the separated instrument without any complication.[3] However, the retrieval of separated instruments is one of the most difficult operations in endodontic treatment, which is time consuming and requires skillful operation, advanced techniques, and professional equipment. In addition, there are considerable risks during the retrieval process, such as ledge formation, refracture of instruments, and perforation or vertical cracks due to over-preparation of root canals.[4—12] Previous studies suggested that separated instruments in the lower segment of the root canal should be treated prudently.[4,7,12—15]

The retrieval rate of separated instruments is affected by multiple factors such as the tooth position, the root canal curvature, the depth, length, type, and material of separated instruments.[5,13,15] However, opinions on the effect of tooth position and the length of separated instruments are controversial.[11,13,15] The depth of the separated instrument and the root canal curvature are considered to be related to the retrieval rate of separated instruments, but the effect of these two factors and the interaction relationship with the other factors are not clear. In this study, we wanted to collect medical information and aid dentists with decision-making before operations. The objective factors were chosen, such as tooth position, root canal curvature, and the depth and length of separated instruments which can be precisely collected or measured with the help of an X-ray image. However, the information about the type of instrument and the material of the instruments cannot be known before the operation, so these two factors are not appropriate to be used as evidence for preoperative evaluation.

Logistic regression has been widely used in investigating the relationship between the discrete responses and a set of independent predictors. The statistical model established with logistic regression can be used to quantify the effect of each covariate and to predict the probability of success for the given covariates. Therefore, to evaluate the retrieval rate of the separated instruments in the lower segment of the curved root canal precisely, the effect and the interaction relationship of multiple factors on the retrieval rate are needed to be quantified via a statistical model.

In this study, we aimed to evaluate the correlation of retrieval rate with objective factors, such as tooth position, root canal curvature, and the depth and length of separated instruments via a retrospective study of clinical cases. Furthermore, a regression equation was established via multivariate logistic regression to quantify the influences of multiple factors on the retrieval rate of separated instruments in the lower segment of the curved root canal. Finally, the equation was verified by new clinical cases.

Materials and methods

Inclusion criteria of the patients

In the retrospective study, 192 patients including 89 males and 103 females with separated instruments in the lower segment of the curved root canal were recruited from the patients who visited Xiamen Stomatological Hospital, Xiamen, China from December 2006 to December 2010. A total of 210 separated instruments in 203 root canals were treated. Inclusion criteria of the patients were: (1) the top of fracture plane was located in the lower segment of the curved root canal; (2) the angle of the root canal curvature was $> 15^{\circ}$; and (3) the root canal retreatment was necessary for the patient.[4,13] All patients were aware of the risk of the treatment and agreed to participate in the study and signed informed consent forms. Ethical approval was obtained from the Ethics Committee of School and Hospital of Stomatology, Wuhan University.

Preoperative measurements

Distant paralleling technique provided a reproducible position for the dental X-ray film. The tooth position was recorded, and the angle and radius of curvature of each root canal was measured following the methodology of Schneider.[16] The depth and length of the separated instruments were measured from the X-ray film. The depth of the separated instruments was defined as the straight line length from the root canal orifice to the fracture of the separated instrument on the X-ray film. The preoperative measurements were completed by one doctor.

Retrieving the separated instruments

The separated instruments were retrieved according to the protocol described by Suter et al[3] under digital optic microscope (DOM, Leica, Wetzlar, Germany). The clinical treatment was performed by one doctor with over> 5-years work experience. The dentine surrounding the coronal end of the separated fragment was removed until the instrument was visible. After the separated fragment was removed, a confirmatory radiograph was taken to reconfirm the condition of the root canal. The criterion of successful retrieval is that the instrument is removed completely without any lateral piercing of the root canal. The criteria for failed retrieval include: (1) the instrument is not removed completely; (2) a by-pass is created and the instrument cannot be removed; and (3) the root canal is perforated during retrieval treatment.

Statistical analysis

All statistical analyses were conducted using Microsoft Excel 2007 and SAS (version 9.2; SAS Institute Inc., Cary, North Carolina, USA). One categorical variable (tooth position) and three continuous variables (root canal curvature, depth and length of separated instruments) were chosen. Pearson Chi-square test for the categorical variable and univariate logistic regression for the continuous variables were performed, respectively, to quantify the correlation between various factors and the retrieval rate of separated instruments. The factors that were correlated to the retrieval rate were selected to establish a statistical formulation via stepwise multivariate logistic analysis. In order to assess the interaction relationship of all included covariates, multi-collinearity of the covariates were analyzed to avoid the negative effect on the multiple linear regressions. The fitting effect of the regression equation was evaluated with a Hosmer-Lemeshow test and the robustness was assessed using area under the curve of the receiver operating characteristic curve. Finally, a regression equation was derived based on the results of multivariates analysis to predict the retrieval rate.

Verification of the regression equation

To verify the regression equation, 63 new cases were recruited. In the verification study, 60 new patients including 27 males and 33 females with 63 separated instruments in 63 root canals were recruited from the patients in Xiamen Hospital of Stomatology from February 2013 to November 2013. Using the double-blind method, one doctor evaluated the tooth of the patients preoperatively, collected the data from the X-ray film, and calculated the retrieval rate using the statistical model; the other five doctors with > 5-years work experience attempted to retrieve the separated instruments using the method which was the same as the retrospective study. Cases with the predicted retrieval rate higher than 50% was judged as a predicted successful case. If the separated instrument of this case was removed successfully, the case would be marked as correctly predicted. Otherwise, the case with the predicted retrieval rate lower than 50% was judged as a predicted failed case. If the retrieval was failed, the case would be marked as correctly predicted as well.

Results

In the retrospective study, 210 cases that conformed to the inclusion criteria were collected. Among them, 164 were successful and 46 failed, with a retrieval rate of 78.1% (164/210).

The relationship between the tooth position and the retrieval rate is depicted in Fig. 1. In 210 cases, 79 out of 101 separated instruments in the upper teeth were retrieved, with a retrieval rate of 78.2%; 85 out of 109 separated instruments in the lower teeth were retrieved, with a retrieval rate of 78.0%. The results demonstrated that there was no significant difference between the retrieval rates of the upper and lower teeth ($P > 0.05$). The retrieval rate of separated instruments in the anterior teeth was 81.8% (18 out of 22 teeth); 44 out of 56 separated instruments in the premolars were retrieved, with a success rate of 78.6%; 102 out of 132 separated instruments in the molars were retrieved, with a success rate of 77.3%. The results showed that there was no significant difference among different tooth position ($P > 0.05$).

The relationship between the root canal curvature and the retrieval rate is depicted in Fig. 2, and the relationship between the depth of the separated instrument and the retrieval rate is shown in Fig. 3. The retrieval rate of separated instruments decreased gradually with the increase of root canal curvature. The retrieval rate of the instruments in the root canals with a curvature angle of 15° was 98.8%, while it decreased dramatically to 15.8% when the curvature angle was 45° (Fig. 2). Likewise, the retrieval rate decreased gradually with an increase in depth of the separated instrument. When the depth of the separated instrument was > 10 mm, the retrieval rate would decrease to 36.7% (Fig. 3). The relationship between the length of the broken instrument and the retrieval rate is depicted in Fig. 4. When the length of the broken instrument was 3—5 mm, the retrieval rate was 67.7%. When the length was > 5 mm, the retrieval rate was 91.3%. Univariate logistic regression analysis (Table 1) showed that the root canal curvature and the depth of the separated instrument were significantly correlated with the retrieval rate ($P < 0.01$). The change of the retrieval rate was not significantly related to the length of the instrument ($P > 0.05$), suggesting the length of the separated instrument was not correlated with the retrieval rate. The variance inflation factor of the root canal curvature and the depth of the separated instrument was 1.52 and 1.36, respectively, implying that these two factors were appropriate for conducting multivariate analysis. The multivariate logistic analysis (Table 2) suggested that the root canal curvature and the depth of the separated instrument were negatively and nonlinearly related to the retrieval rate, but their magnitudes changed. Therefore, the effect and the interaction relationship of multi-factors on the retrieval rate were precisely quantified through multivariate analysis.

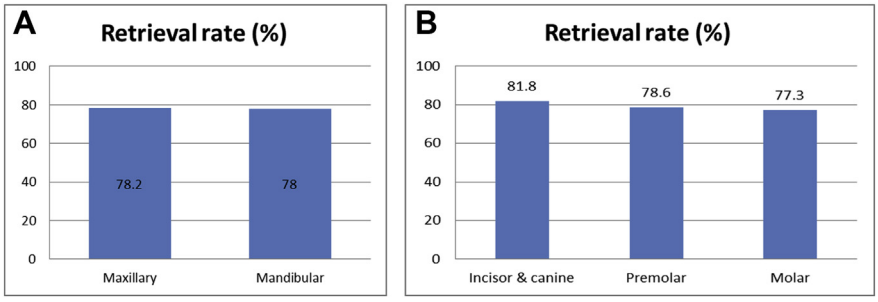

Figure 1 The retrieval rate of different tooth positions and different tooth types. (A) Retrieval rate of the maxillary teeth and the mandibular teeth; (B) Retrieval rate of the incisors/canines, the premolars and the molars.

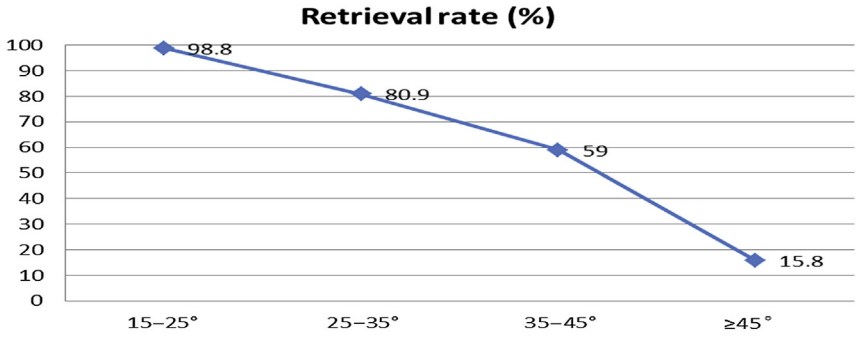

Figure 2 Retrieval rate of different curvatures of the root canals.

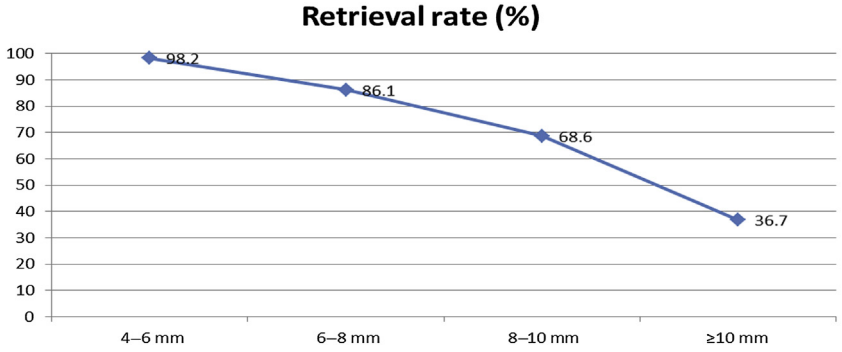

Figure 3 Retrieval rate of different depths of the separated instrument.

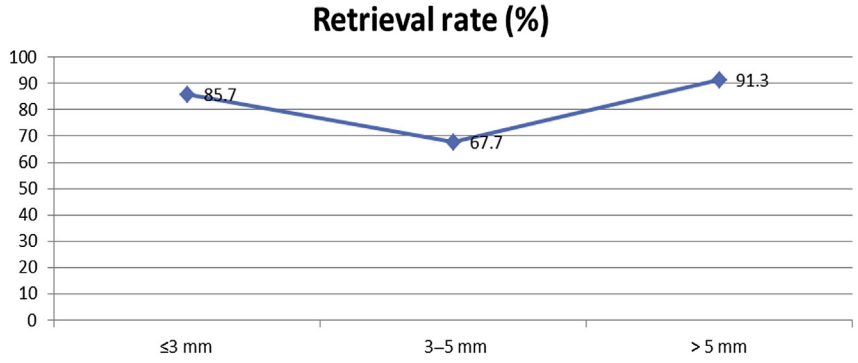

Figure 4 Retrieval rate of different lengths of the broken instrument.

Table 1 Results of univariate analysis.

Covariate	β	Odds ratio	95% CI	P
Cur	−0.16	0.85	(0.81, 0.90)	<0.0001
Depth	−0.56	0.57	(0.48, 0.69)	<0.0001
Length	−0.08	0.92	(0.74, 1.16)	0.4811

CI = confidence interval; Cur = root canal curvature; depth = depth of broken instruments.

Table 2 Results of multivariate analysis.

Covariates	β	Odds ratio	95% CI	std β	P
Intercept	20.6683	—	—	—	<0.0001
Cur	−0.2957	0.74	(0.67, 0.83)	−1.99	<0.0001
Depth	−1.2158	0.30	(0.19, 0.46)	−1.45	<0.0001

CI = confidence interval; Cur = root canal curvature; depth = depth of broken instruments; std β = standard β.

A regression equation was derived via stepwise multivariate logistic analysis:

$$p = 1 - \frac{1}{[1 + \exp(20.6683 - 0.2957 * Cur - 1.2158 * Dep)]} \quad (1)$$

(more details seen in Table 2). p = the predicted retrieval rate; Cur = the root canal curvature; Dep = the depth of broken instrument.

The result of the Hosmer-Lemeshow test showed that the prediction and observation values of the model were highly consistent ($P > 0.05$), suggesting that the fitting effect of the model was acceptable. The area under the *receiver operating characteristic* was 0.9905 indicating that this model was fitted very well with the sample data. The results of the model diagnosis confirmed that the model was robust, which demonstrated that the model could discriminate the possibility of removal success from failure (see Fig. 5).

The accuracy rate of the statistical model was evaluated in the verification study. The data of root canal curvature and the depth of the separated instrument were substituted into the equation to calculate the predicted retrieval rate of the case. In 53 cases which were predicted to be successful, 50 cases succeeded in practice, indicating that the accuracy rate of the prediction of successful retrieval was 94.3%. In 10 cases which were predicted to be failed, eight cases were failed in practice, indicating that the accuracy rate of the prediction of failed retrieval was 80.0%.

The reasons of failure also have been analyzed. In the retrospective study and the verification study, lateral perforation was the main reason of failure (63.0% and 63.6%). Other reasons for failure included: (1) the instruments was separated again (26.1% and 18.2%); (2) the separated instruments failed to be retrieved (8.7% and 18.2%); and (3) the separated instrument was pushed out of the root apical foramen during the operation (2.2% only in the retrospective study).

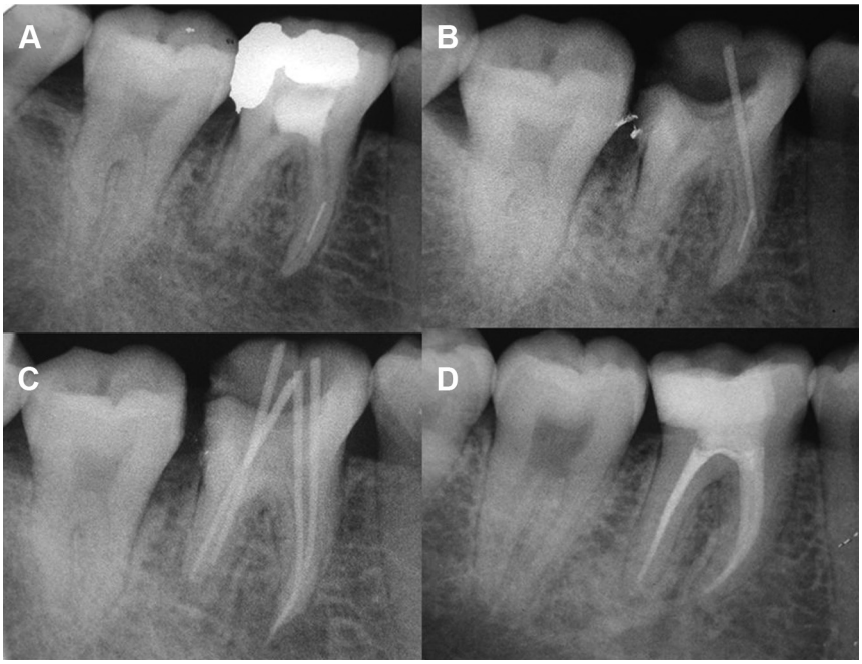

Figure 5 Retrieval of the separated instruments from a curvature root canal. (A) A separated instrument was in the lower segment of the curvature root canal. The curvature angle of the root canal was 31° and the depth of the separated instruments was 7 mm. The retrieval rate calculated from the regression equation was 95.2%, which predicted that the successful retrieval rate was high. (B) The dentine above the separated fragment was removed until the instrument was visible, and a straight pathway was made to the separated instrument. (C) The separated instrument was successfully retrieved, and the master gutta-percha cones were tried in the root canals. (D) The root canals were completely filled.

Discussion

Instrument separation is a common complication in root canal therapy. A clinical decision on whether to retrieve the broken instruments or not must be made by a dentist prudently. For clinicians, a reasonable alternative choice of removing the separated instruments or not must be made under thorough consideration of the benefits and the risks of separated instrument retrieval. The decision that must be made mainly depends upon two factors: (1) whether the separated instruments in the root canal will negatively influence the therapeutic effect; and (2) the success rate of removing separated instruments. For the first factor, McGuigan[17] suggested that the separated instrument in a tooth without apical lesions had no significant influence on the prognosis; however, the separated instrument significantly affected the prognosis of the tooth with apical lesions. For the prediction of the retrieval rate of the separated instruments, there is no perfect theory or method to solve this problem. Most studies suggest that the success rate of retrieval in the upper segment or in the straighter root canal was higher than in the lower segment of the curved root canal.[4,7,12–15] However, most of the instruments were separated in the apical third of root canals,[2,18,19] and the curved root canal itself was one of the most important factors for instrument separation.[1,2,20–23] Accurately predicting the success rate of retrieval is essential for clinical decision-making to deal with cases with separated instruments in the lower segment of the curved root canal.

Evaluating the retrieval rate scientifically is essential for the assessment of clinical risks and for providing a reliable evidence for the clinical decision-making. The success rate of retrieving separated instruments is influenced by multiple factors, so clinical cases of large sample size were collected to analyze the correlation between these factors and the retrieval rate. The factors with significant correlation were selected to establish a statistical model for predicting the success rate of separated instrument retrieval. These factors must be objective and measurable. Based on these principles, the tooth position, the root canal curvature, and the depth and length of the broken instrument were selected as covariates in this study.

Controversies about the influence of the tooth position and the length of the separated instrument on the retrieval rate still exist. The result of this study showed that there were no significant difference between the retrieval rate of upper and lower teeth, and no significant difference among anterior teeth, premolar, and molar. These findings are similar to the results reported by Suter et al.[3] Though some studies indicated that the retrieval rate of separated instruments in molars was lower than that in anterior teeth,[12,24] the anatomical differences between anterior and posterior teeth were ignored in these studies. Clinical data manifested that the incidence of instrument separation was the highest in the mesio-buccal root canal of the molar,[17] but it should be noted that the incidence of curvature was much higher in the mesio-buccal root canal of molars than in anterior teeth. The results of these studies suggest that root canal curvature instead of the tooth position might affect the success rate of separated instrument retrieval.

Moreover, the results of this study suggest that the length of the separated instrument insignificantly correlates with the retrieval rate, consistent with previous research.[3,12,24] Hülsmann and Schinkel[13] reported that the retrieval rate was the lowest when the length of the separated instrument was 3–5 mm, but was the highest

Table 3 Retrieval rate of different combinations of root canal curvature and depths of the separated instruments outputted from the model.[a]

Depth (mm)	Cur (°)											
	15	16	17–20	21–24	25–28	29–32	33–37	38–41	42–45	46–49	50–53	≥54
4	>99.9	>99.9	>99.9	>99.9	>99.9	>99.8	>99.2	>97.5	>92.4	>78.8	>53.3	<45.9
5	>99.9	>99.9	>99.9	>99.9	>99.8	>99.4	>97.4	>92.1	>78.2	>52.5	<45.2	<20.2
6	>99.9	>99.9	>99.9	>99.8	>99.3	>98.0	>91.9	>77.7	>51.7	<44.5	<19.6	<7.0
7	>99.9	>99.9	>99.8	>99.3	>97.9	>93.6	>77.1	>50.8	<43.5	<19.1	<6.8	<2.2
8	>99.8	>99.7	>99.3	>97.9	>93.4	>81.4	>50.0	<42.7	<18.6	<6.6	<2.1	<0.7
9	>99.4	>99.3	>97.8	>93.2	>80.9	>56.6	<49.3	<18.1	<6.4	<2.1	<0.7	<0.2
10	>98.3	>97.7	>93.0	>80.4	>55.7	<48.4	<22.4	<6.2	<2.0	<0.7	<0.2	<0.06
11	>94.5	>92.8	>79.9	>54.9	<47.6	<21.8	<7.9	<2.0	<0.6	<0.2	<0.06	<0.02
12	>83.7	>79.3	>54.1	<46.8	<21.2	<7.7	<2.5	<0.6	<0.2	<0.06	<0.02	<0.006
13	>60.5	>53.3	<46	<20.7	<7.4	<2.4	<0.8	<0.2	<0.06	<0.02	<0.005	<0.002
≥14	<31.3	<25.3	<20.5	<7.2	<2.5	<0.8	<0.3	<0.06	<0.02	<0.005	<0.002	<0.0005

Cur = root canal curvature; depth = depth of broken instruments.

[a] For convenient usage of the statistical model, the predicted retrieval rate of different combinations of the root canal curvature and the depth of the separated instruments have been calculated from the regression equation in Table 3. The horizontal title is the root canal curvature, increasing from 15° to > 54°. The vertical title is the depth of the separated instruments, increasing from 4 mm to > 14 mm. Clinicians can get the predicted retrieval rate from the table by measuring the curvature and the depth. If the predicted retrieval rate is > 0.5, the retrieval rate will be high enough to attempt to retrieve the separated instruments; if the predicted retrieval rate is < 0.5, the retrieval rate will not be high enough. In this condition, a by-pass or surgery is needed to retrieve the separated instruments, instead of trying to retrieve the separated instruments nonsurgically under a microscope.

when the length was > 5 mm. However, McGuigan et al[15] reported that there was no evidence showing that the length of the broken instrument had a significant influence on the retrieval rate. When the length of the separated instrument was < 3 mm, it is easier for the doctor to remove the resistance and the success rate of retrieval was higher. In cases where the length of the separated instrument was > 5 mm, the depth of the separated instrument was often shallow enough for exposing the upper segment of the separated instrument and retrieving it.

The root canal curvature and the depth of the separated instrument were correlated with the retrieval rate significantly. With the increment of curvature and depth, the retrieval rate decreased significantly. This result was similar to previous research.[4,7,12–14] It was notable that Suter et al[3] found no significant differences of the retrieval rate of the separated instruments in different positions of the root canal, but the risk of perforation was increased when the separated instrument was at the apical third of the root canal. With the increment of the curvature of the root, to expose and retrieve the separated instruments is getting harder and harder. In a curved root canal, it is common to see the separated instruments self-locked in the root and an excess of dentin needs to be removed to build the access pathway. As a result, complications, such as lateral perforation and root fractures increased and the success rate of retrieval decreased. The results of this study showed that the root canal curvature and the depth of the separated instrument were significantly correlated to the retrieval rate, and the multi-colinear diagnostic results showed that these two factors are not significantly correlated. Also, from a clinical point of view, both factors are independent and not affected by each other. Thus, the root canal curvature and the depth of separated instruments were the appropriate factors to predict the retrieval rate.

To ensure reliability, this statistical model was evaluated and diagnosed. The results showed that the model was robust and the effect of sample data fitting was good. An additional 63 new clinical cases were used to verify the evaluation efficiency of the model. The results showed that the accurate rates of the successful and failed retrieval predictions were both acceptable, suggesting that the evaluation efficiency of the model was reliable. For convenient usage of the statistical model, the predicted retrieval rate of different combinations of the root canal curvature and the depth of the separated instruments have been calculated using the regression equation (Table 3). The clinicians can find out the retrieval rate directly by measuring the curvature and the depth, and get a reference to use in decision-making.

In conclusion, the tooth position and the length of the separated instrument are not significantly correlated with the retrieval rate of separated instruments in the lower segment of curved root canals. The root canal curvature and the depth of separated instruments are the main factors affecting the retrieval rate of separated instruments in the lower segment of curved root canals, and a regression equation has been established to predict the retrieval rate. The retrieval rate of the separated instruments can be predicted scientifically using a regression equation to aid clinical decision-making.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

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